

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
29 August 2002 (29.08.2002)

PCT

(10) International Publication Number
WO 02/066405 A1

(51) International Patent Classification⁷: C07C 2/32, B01J 31/22

(21) International Application Number: PCT/NL02/00119

(22) International Filing Date: 22 February 2002 (22.02.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PCT/NL01/149 22 February 2001 (22.02.2001) NL

(71) Applicant (*for all designated States except US*): **STICHTING DUTCH POLYMER INSTITUTE** [NL/NL]; Den Dolech 2, MA 1.13, NL-5612 AZ Eindhoven (NL).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **DECKERS, Patrick, Jozef, Wilhelmus** [NL/NL]; 6, Bankastraal, NL-9715 CA Groningen (NL). **HESSEN, Bart** [NL/NL]; Heideweg 10, NL-9824 TJ Noordwijk (NL).

(74) Agent: **VAN DER KLOET-DORLEIJN, G., W., F.**; Exter, Polak & Charlouis B.V., P.O. Box 3241, NL-2280 GE Rijswijk (NL).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: CATALYST SYSTEM FOR THE TRIMERISATION OF OLEFINS

(57) Abstract: The invention relates to a catalyst system for the selective trimerisation of olefins, which system is based on a titanium complex of formula $(\text{Cp-B}(\text{R})_n\text{Ar})\text{TiR}^1_3$, wherein: Cp is a cyclopentadienyl type ligand, optionally substituted, B is a bridging group, based on a single atom selected from the groups 13 to 16 inclusive of the Periodic System, Ar is a aromatic group, optionally substituted, R is, independently, hydrogen, or a hydrocarbon residue, optionally being substituted and optionally containing heteroatoms, or groups R and B are joined together to form a ring, N is an integer equal to the (valency of B minus 2), and R¹ is a mono-anionic group, and further comprises an activator. The present catalyst system obviates the use of toxic chromium compounds.



WO 02/066405 A1

Title: Catalyst system for the trimerisation of olefins.

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of PCT-application
PCT/NL01/00149, filed 22 February 2001, the disclosure thereof being
5 incorporated by reference.

DESCRIPTION

The invention relates to a catalyst system for the selective
trimerisation of olefins, which system comprises a transition metal
10 complex.

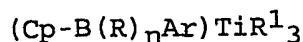
Such a catalyst system for trimerisation of olefins is known
from EP-A-0608447 and consists of a combination of a transition metal
source, a pyrrole containing compound and a metal alkyl in an electron
donor solvent. The transition metal source consists of a chromium,
15 nickel, cobalt, or iron compound, preferably a chromium compound is
used.

Because chromium compounds are highly toxic, and therefore need
special handling precautions, a catalyst system for the trimerisation
of olefins, which is not based on a chromium compound is needed.

20 A catalyst system has now been found which is not based on a
chromium compound, but still shows a high selectivity in the
trimerisation of olefins with respect to the trimerisation product.

More specifically, the invention relates to a catalyst system as
indicated above, which is characterized in that said catalyst system
25 comprises

- a) a half-sandwich substituted cyclopentadienyl titanium complex
of formula



wherein

30 Cp is a cyclopentadienyl type ligand, optionally substituted,
B is a bridging group, based on a single atom selected from
the groups 13 to 16 inclusive of the Periodic System,
Ar is a aromatic group, optionally substituted,
R is, independently, hydrogen, or a hydrocarbon residue,
35 optionally being substituted and optionally containing

heteroatoms, or groups R and B are joined together to form a ring,

n is an integer equal to the (valency of B minus 2), and

R¹ is a mono-anionic group, and

5 b) an activator.

It is observed that the catalyst system as disclosed in EP-A-0608447 is preferably a chromium catalyst, but a catalytic system based on a titanium compound, more specifically TiO(acac)₂, was also tested as a catalyst for the trimerisation of ethylene. The
10 selectivity for hexene-1 was in that case nevertheless rather low. A high selectivity for hexene-1 is industrially very important because of the use of hexene-1 as starting material for the preparation of different kinds of (co)polymers.

It is further observed that trimerisation is in the above-
15 mentioned reference and in the present disclosure defined as the combination of one or more kinds of olefins, wherein the number of olefin, i.e. double, bonds is reduced by two. The term "trimerisation" is thus intended to include "co-trimerisation". So, for example, the number of olefin bonds in the combination of three ethylene units is
20 reduced by two, to one olefin bond, in 1-hexene.

A half-sandwich substituted cyclopentadienyl titanium complex as a catalyst, in the presence of a co-catalyst, is known for example from Macromol. 1999, 32, 4491-4493. This titanium complex does nevertheless not have a bridging group in its structure; moreover, the
25 catalyst system is used for the synthesis of polyethylenes containing significant amounts of butyl branches, and is thus used in a polymerisation process.

As is known from EP-A-0 780 353, the properties of a polymer do not change markedly with the addition or removal of one or a few
30 repeating units, contrary to the properties of a product obtained by oligomerisation or trimerisation. A polymerisation catalyst thus results in completely different products than a trimerisation catalyst does.

Half-sandwich cyclopentadienyl titanium complexes of formula
35 (CpB(R)₂Ar)TiMe₃ and (CpB(R)₂Ar)TiCl₃ are known per se from J. Saßmannshausen et al., J. Organomet. Chem. 1999, 592, 84-94. In these known complexes B(R)₂Ar can be CMe₂Ph, CHPh₂ or SiMe₂Ph. These complexes were only used as polymerization catalysts; there is no indication at all that these known catalysts could effectively be

used for the selective trimerisation of olefins. On the contrary: it is said that the effect of a comparatively weakly coordinated pendant ligand, such as phenyl, on the behaviour of a polymerisation catalyst is difficult to predict. Moreover, a possible favourable effect of a catalyst having a bridging group only consisting of a single atom, for a trimerisation process of ethene to obtain hexene-1, is not mentioned or suggested in this reference.

As mentioned before, Cp is a cyclopentadienyl type ligand, which is optionally substituted.

More preferably, Cp is a cyclopentadienyl, indenyl or fluorenyl group, which may be substituted or not with one to five (cyclopentadienyl), one to seven (indenyl) or one to nine (fluorenyl) substituent alkyl or silyl groups, especially methyl or trimethylsilyl groups.

In the catalyst system according to the invention Ar is an aromatic group, which is optionally substituted; examples thereof are phenyl, naphthalene, anthracene or phenanthrene. This enumeration is not to be regarded as limitative; other aromatic groups can also be used, provided that a coordination complex, based on π -electrons of said group, together with titanium is present.

As mentioned above, B is a bridging group based on a single atom selected from the groups 13 to 16 inclusive, preferably B, C, N, O, Si, P, S; more preferably C or Si; most preferably C.

In a preferred embodiment of the invention, the catalyst system comprises a complex of the above given formula, wherein the single atom forming the basis of said group B consists of carbon or silicon, Ar is phenyl, optionally substituted or being part of a larger aromatic entity,

R^1 is a halide, or mono-anionic hydrocarbon residue optionally containing heteroatoms, and
n is 2, then R is a mono-anionic hydrocarbon residue, optionally containing heteroatoms, or
n is 1, then R is a di-anionic hydrocarbon residue, optionally containing heteroatoms.

Expediently, the catalyst system of the invention comprises a titanium complex of the above given formula, wherein Cp is a cyclopentadienyl type ligand being substituted, besides said B-(R)_n group, with 1 to 8 groups of formula -YR₂R₃R₄ in which Y is C or Si and R₂, R₃ and R₄ are, independently, H, halogen, lower alkyl, aryl, lower-alkyl-aryl, aryl-lower alkyl residue, wherein said alkyl and

aryl are independently substituted or not with one or more lower alkyl residues, said alkyl and aryl residues being independently provided or not with at least one heteroatom, selected from halogen, nitrogen, oxygen, sulphur and phosphor.

5 It is in this respect observed that by "provided" is to be understood that said heteroatom(s) can be incorporated in the hydrocarbon chain, as well as be present as or in a substituent group.

Expediently, said lower alkyl residues, being the same or
10 different to each other, are linear or branched C₁-C₅ alkyl residues, more specifically methyl.

In a further preferred embodiment of the present catalyst system, said above mentioned aryl group in the alkyl aryl or aryl alkyl residue is a phenyl group.

15 Said halogen is preferably fluorine or chlorine.

More preferably the catalyst system of the invention comprises a titanium complex of the above given formula, wherein Ar is a phenyl group, substituted or not at the meta-or para-position(s),

20 B is based on a carbon atom,

n is 2, then groups R are, independently, methyl, or ethyl; or

n is 1, then group R is =CH₂, or forms when R is C₄H₈ or C₅H₁₀

together with group B a dianionic cyclic group,

Cp is C₅H₄ or C₅H₃(SiMe₃), and

25 R¹ is chlorine, methyl, or benzyl.

The half-sandwich, substituted cyclopentadienyl titanium complex, forming a part of the present catalyst system, is in a preferred embodiment supported by a carrier. This carrier consists expediently either of a metal oxide, which is selected from the group
30 consisting of alumina, boria, magnesia, thoria, zirconia, silica, or mixtures thereof, or it consists of a polymeric material.

As indicated above, the present catalyst system comprises an activator. Said activator is preferably methylalumoxane, a salt of a non-coordinating anion, or a Lewis acid capable of abstracting an
35 anion from said transition metal complex and thus generating a cationic transition metal species with a non-coordinating anion.

An example of a salt of a non-coordinating anion is N,N-dimethylanilinium tetrakis(pentafluorophenyl)borate, while such a Lewis acid is for example B(C₆F₅)₃. It is in this respect observed

that any activator can be used provided that it is able to generate a cationic transition metal species with a non-coordinating anion. The term "non-coordinating anion" is meant to indicate the anionic part or derivative of the activator, which not or only weakly coordinates to the cationic form of the present catalyst system.

Preferably the activator is methylalumoxane (also known as MAO). The molar ratio of Ti:Al is expediently from 1:100 to 1:1000.

The present catalyst system can further also comprise a scavenger. Examples of a scavenger are $i\text{-Bu}_3\text{Al}$ and $(i\text{-Bu}_2\text{Al})_2\text{O}$. A scavenger is normally used to scavenge impurities from a polymerisation medium to obtain a high productivity.

The invention further relates to a process to trimerize olefinic compounds which comprises carrying out said trimerisation in the presence of a catalyst system, as described above, under trimerisation conditions. Such a trimerisation also comprises co-trimerisation according to the definition given before.

The olefin to be trimerized is preferably selected from $\text{C}_2\text{-C}_{20}$ olefins or mixtures of two or more of these olefins. The preferred olefins are ethylene and 1-butene, more preferably ethylene.

The temperature is preferably in the range of from 20-150°C, at a pressure in the range of from 1,5 to 3 MPa.

The invention will further be explained in the following examples.

25 Experimental section

General considerations

All experiments were performed under a nitrogen atmosphere using standard Schlenk and glovebox techniques. Deuterated solvents (Aldrich, Acros) were dried over Na/K alloy and vacuum transferred before use. Cyclooctane (Aldrich, used as internal standard) was distilled from Na prior to use. Toluene (Aldrich, anhydrous, 99,8%) was passed over columns of Al_2O_3 (Fluka), BASF R3-11 supported Cu oxygen and molecular sieves (Aldrich, 4Å). Diethyl ether and THF (Aldrich) were dried over Al_2O_3 (Fluka) and the other solvents (Aldrich) were dried over molecular sieves (Aldrich, 4Å). Ethene (AGA polymer grade) was passed over BASF R3-11 supported Cu oxygen scavenger and molecular sieves (Aldrich, 4Å).

The compounds 6,6-pentamethylenefulvene, $\text{C}_5\text{H}_5\text{CH}_2\text{Ph}$, $(\text{C}_5\text{H}_4\text{C}(\text{=CH}_2)\text{Ph})\text{Li}$, $(\text{C}_5\text{H}_4\text{CMe}_2\text{Ph})\text{TiCl}_3$ (the catalyst used in

Example 1), $(C_5H_4SiMe_2Ph)TiCl_3$ (the catalyst used in Example 3), $(C_5H_4CMe_2-3,5-MeC_6H_3)TiCl_3$ (the catalyst used in Example 2) and $B(C_6F_5)_3$ were prepared according to procedures known as such. 6,6-Diethylfulvene was prepared analogously to 6,6-pentamethylenefulvene from cyclopentadiene and 3-pentanone. $(C_5H_4CMe_2Ph)TiMe_3$ (used in Examples 10 and 11) was prepared through modification of a known procedure by reaction of $(C_5H_4CMe_2Ph)TiCl_3$ with either Me_2Mg or $MeMgI$. The preparations of other titanium complexes are disclosed hereafter in the Preparation Examples A to F.

10 A toluene solution of MAO (26 wt%, Akzo Nobel Chemicals), MAO supported on silica (5 wt%, Witco) and $[PhNMe_2H][B(C_6F_5)_4]$ (Akzo Nobel Chemicals) were used as such.

NMR spectra were recorded on Varian Gemini 200/300 and Unity 500 spectrometers.

15 The 1H NMR spectra were referenced to resonances of residual protons in the deuterated solvents. Chemical shifts (δ) are given relative to tetramethylsilane (downfield shifts are positive). GC analyses were performed on a HP 6890 instrument equipped with a HP-1 dimethylpolysiloxane column (19095 Z-123). GC-MS analyses were
20 conducted using a HP 5973 mass-selective detector attached to a HP 6890 GC instrument. Elemental analyses are the average of a least two independent determinations.

Preparation example A

25 Preparation of $(C_5H_4CH_2Ph)TiCl_3$, to be used in Example 4.

a) Preparation of $(C_5H_4CH_2Ph)Li$

To a solution of 11.3 mmol n-BuLi in 30 ml of diethyl ether/hexane at $-40^\circ C$, 1.87 g (12.0 mmol) of $CpHCH_2Ph$ [2] was added dropwise. The reaction mixture was allowed to warm to room
30 temperature and stirred overnight. The solvents were removed in vacuo. The white residue was stripped with pentane. After rinsing with 3x 10 ml of pentane and after drying in vacuo 1.55 g (9.6 mmol, 85%) of a white solid was isolated. - 1H NMR (300 MHz, $THF-d_8$): δ 8.04-7.92 (m, 4H, Ph o- and m-H), 7.82 (m, 1H, Ph p-H), 6.33 (t, $^3J_{HH}$
35 = 2.6 Hz, 2H, Cp), 6.29 (t, $^3J_{HH}$ = 2.6 Hz, 2H, Cp), 4.61 (s, 2H, CH_2) - ^{13}C NMR (75.4 MHz, $THF-d_8$): δ 148.2 (Ph C ipso), 130.5 (Ph o- or m-CH), 129.5 (Ph o- or m-CH), 126.3 (Ph p-CH), 120.0 (Cp C ipso), 105.1 (Cp CH), 103.9 (Cp CH), 39.0 (CH_2)

b) Preparation of $(C_5H_4CH_2Ph)TiCl_3$

To a solution of 1.42 g (8.8 mmol) $(CpCH_2Ph)Li$ in 40 ml of methylene chloride, cooled at $-40\text{ }^{\circ}C$, 0.96 ml (1.7 g, 8.9 mmol) titanium(IV) chloride was added. The reaction mixture was stirred at ambient temperatures overnight. The methylene chloride was removed in vacuo and the green-brown residue was stripped with pentane. After extraction with toluene, the extract was evaporated in vacuo and the extract residue was dissolved in methylene chloride. Brown crystals were obtained after cooling to $-40\text{ }^{\circ}C$. Yield: 1.58 g (5.1 mmol, 58%)

10 - 1H NMR (300 MHz, C_6D_6): δ 7.09-7.03 (m, 3H, Ph *m*- and *p*-H), 6.82 (m, 2H, Ph *o*-H), 5.98 (m, 4H, Cp), 3.71 (s, 2H, CH_2) - ^{13}C NMR (75.4 MHz, C_6D_6): δ 142.9, 138.3 (Ph and Cp C *ipso*), 128.9, 127.2 (Ph CH, one signal overlapped by solvent), 123.6, 123.2 (Cp CH), 37.7 (CH_2) - Anal. Calcd for $C_{12}H_{11}TiCl_3$: C, 46.57; H, 3.58; Ti, 15.48. Found: C, 15 47.07; H, 3.75, Ti, 15.38.

Preparation example B**Preparation of $(C_5H_4CET_2Ph)TiCl_3$, to be used in Example 5.****a) Preparation of $C_5H_4(TMS)CET_2Ph$**

20 To a solution of 4.85 g (58 mmol) $PhLi$ in 200 ml of diethyl ether, cooled at $-50\text{ }^{\circ}C$, 8.0 g (60 mmol) of 6,6-diethyl fulvene [1] was added dropwise. The reaction mixture was allowed to warm to room temperature and was stirred for 3 hours. After 3 hours the yellow solution was cooled with an ice bath and 7.6 ml (6.5 g, 60 mmol) of trimethylsilyl chloride was added dropwise. The mixture was allowed to warm to room temperature and stirred overnight. The reaction mixture was poured into 250 ml of ice water. The water layer was extracted with 2x 100 ml of light petroleum, after which the combined organic layers were rinsed with 200 ml of brine. The organic phase

25 was dried on $MgSO_4$. After evaporating the low-boiling volatiles in vacuo, the residue was distilled using a Kogelruhr-apparatus. The product distilled at $110\text{ }^{\circ}C$ at 0.5 mm Hg as a mixture of isomers. Yield: 9.21 g (32 mmol, 55%) - 1H NMR (300 MHz, $CDCl_3$, main isomer): δ 7.28 (m, 4H, Ph *o*- and *m*-H), 7.18 (m, 1H, Ph *p*-H), 6.40 (m, 1H, C_5H_4), 6.31 (s, 1H, C_5H_4), 6.22 (m, 1H, C_5H_4), 3.27 (s, 1H, C_5H_4), 2.02 (m, 4H, C- $\underline{CH_2}$ - CH_3), 0.72 (m, 6H, C- $\underline{CH_2}$ - $\underline{CH_3}$), 0.06 (s, 9H, TMS)

35

b) Preparation of $(C_5H_4CET_2Ph)TiCl_3$

To a solution of 6.30 g (22 mmol) of A.1 in 40 ml of methylene

chloride, cooled at $-40\text{ }^{\circ}\text{C}$, 2.45 ml (4.2 g, 22 mmol) of titanium chloride was added. The mixture was allowed to warm to room temperature and stirred overnight. The methylene chloride was removed in vacuo and the residue was stripped with pentane. Extraction with 5 methylene chloride and cooling to $-60\text{ }^{\circ}\text{C}$ afforded red-brown crystals of the title compound. Yield: 5.63 g (15.3 mmol, 70%) - ^1H NMR (300 MHz, C_6D_6): δ 7.24 (d, $^3J_{\text{HH}} = 7.3\text{ Hz}$, 2H, Ph o-H), 7.17 (t, $^3J_{\text{HH}} = 7.3\text{ Hz}$, 2H, Ph m-H), 7.06 (t, $^3J_{\text{HH}} = 7.3\text{ Hz}$, 1H, Ph p-H), 6.26 (t, $^3J_{\text{HH}} = 2.8\text{ Hz}$, 2H, Cp), 6.04 (t, $^3J_{\text{HH}} = 2.8\text{ Hz}$, 2H, Cp), 2.06 (m (dq), 2H, C- $\text{CH}_2\text{-CH}_3$), 1.86 (m (dq), 2H, C- $\text{CH}_2\text{-CH}_3$), 0.51 (t, $^3J_{\text{HH}} = 7.3\text{ Hz}$, 6H, C- $\text{CH}_2\text{-CH}_3$) - ^{13}C NMR (75.4 MHz, C_6D_6): δ 154.8 (Ph C ipso), 142.1 (Cp C ipso), 128.8 (Ph o-CH), 128.3 (Ph m-CH, overlap with solvent), 127.2 (Ph p-CH), 123.1, 121.8 (Cp CH), 48.6 ($\text{C}(\text{C}_2\text{H}_5)_2$ ipso), 29.3 (C- $\text{CH}_2\text{-CH}_3$), 8.5 (C- $\text{CH}_2\text{-CH}_3$) - Anal. Calcd for $\text{C}_{16}\text{H}_{19}\text{TiCl}_3$: C, 52.57; H, 5.24. 15 Found: C, 52.75; H, 5.27.

Preparation example C

Preparation of $\{\text{CpC}[(\text{CH}_2)_5]\text{Ph}\}\text{TiCl}_3$, to be used in Example 6

a) Preparation of $\text{C}_5\text{H}_4(\text{TMS})\text{C}[(\text{CH}_2)_5]\text{Ph}$

20 To a solution of 4.00 g (48 mmol) PhLi in 200 ml of diethyl ether, cooled at $-50\text{ }^{\circ}\text{C}$, 6.95 g (48 mmol) of 6,6-pentamethylenefulvene [1] was added dropwise. The reaction mixture was allowed to warm to room temperature and was stirred for 3 hours. After 3 hours the yellow solution was cooled with an ice bath and 6.4 25 ml (5.5 g, 51 mmol) of trimethylsilyl chloride was added dropwise. The mixture was allowed to warm to room temperature and stirred overnight. The reaction mixture was poured into 250 ml of ice water. The water layer was extracted with 2x 100 ml of light petroleum, after which the combined organic layers were rinsed with 200 ml of 30 brine. The organic phase was dried on MgSO_4 . After evaporating the low-boiling volatiles in vacuo, the residue was distilled using a Kogelruhr-apparatus. The product distilled at $165\text{ }^{\circ}\text{C}$ at 0.4 torr as a mixture of isomers. Yield: 8.96 g (30 mmol, 63%) - ^1H NMR (300 MHz, CDCl_3 , main isomer): δ 7.40 (m, 2H, Ph o-H), 7.33 (m, 2H, Ph m-H), 7.15 (m, 1H, Ph p-H), 6.43 (m, 2H, C_5H_4), 6.15 (s, 1H, C_5H_4), 3.27 (s, 1H, C_5H_4), 2.17 (m, 4H, $\alpha\text{-CH}_2$), 1.65-1.40 (m, 6H, $\beta\text{-}$ and $\gamma\text{-CH}_2$), - 0.03 (s, 9H, TMS)

b) Preparation of $\{\text{C}_5\text{H}_4\text{C}[(\text{CH}_2)_5]\text{Ph}\}\text{TiCl}_3$

Titanium chloride (1.4 ml, 2.4 g, 12.7 mmol) was added to a solution of 3.70 g (12.5 mmol) of $C_5H_4(TMS)C[(CH_2)_5]Ph$ in 40 ml of methylene chloride, cooled at $-40\text{ }^\circ C$. The reaction mixture was allowed to warm to room temperature and was stirred overnight. The methylene chloride was removed in vacuo and the residue was stripped with pentane. The residue was extracted with methylene chloride. Crystallization from a 1:1 mixture of CH_2Cl_2 :pentane afforded red-brown crystals of the desired compound in 78% yield (3.68 g, 9.7 mmol). - 1H NMR (300 MHz, C_6D_6): δ 7.16-7.06 (m, 4H, Ph o- and m-H), 7.01 (m, 1H, Ph p-H), 6.31 (t, $^3J_{HH} = 2.8\text{ Hz}$, 2H, Cp), 5.97 (t, $^3J_{HH} = 2.8\text{ Hz}$, 2H, Cp), 2.45 (d, $^2J_{HH} = 13.2\text{ Hz}$, 2H, α -CH₂ (eq)), 1.88 (m, 2H, α -CH₂ (ax)), 1.37 (br, 3H, β - and γ -CH₂), 1.25-1.05 (m, 3H, β - and γ -CH₂) - ^{13}C NMR (75.4 MHz, C_6D_6): δ 156.0 (Ph C *ipso*), 142.1 (Cp C *ipso*), 129.2 (Ph o-CH), 127.9 (Ph m-CH), 126.8 (Ph p-CH), 123.2, 120.9 (Cp CH), 45.1 ($C[(CH_2)_5]$ *ipso*), 35.8 (α -CH₂), 26.1 (γ -CH₂), 22.4 (β -CH₂) - Anal. Calcd for $C_{17}H_{19}TiCl_3$: C, 54.08; H, 5.07; Ti, 12.69. Found: C, 53.93; H, 4.90; Ti, 12.62.

Preparation example D

20 Preparation of $[C_5H_4C(=CH_2)Ph]TiCl_3$, to be used in Example 7

To a solution of 0.61 ml (1.06 g, 5.6 mmol) titanium chloride in 40 ml of methylene chloride, cooled at $-50\text{ }^\circ C$, 1.80 g (5.6 mmol) $[C_5H_4C(=CH_2)Ph]Li$ was added. The reaction mixture was allowed to warm to room temperature and was stirred overnight. The volatiles were removed in vacuo and the green-black residue was stripped with pentane. Extraction with pentane afforded small analytically pure amounts of the desired compound. - 1H NMR (300 MHz, C_6D_6): δ 7.2-7.05 (m, 5H, Ph), 6.35 (t, $^3J_{HH} = 2.7\text{ Hz}$, 2H, Cp), 6.01 (t, $^3J_{HH} = 2.7\text{ Hz}$, 2H, Cp), 5.58 (s, 1H, =CH₂), 5.20 (s, 1H, =CH₂) - ^{13}C NMR (75.4 MHz, C_6D_6): δ 142.5 (Ph C *ipso*), 139.7 (Cp C *ipso*), 139.6 ($C(=CH_2)$ *ipso*), 128.8, 128.7, 128.5 (Ph CH), 123.4, 121.1 (Cp CH), 120.5 ($C(=CH_2)$) - Anal. Calcd for $C_{13}H_{11}TiCl_3$: C, 48.57; H, 3.45; Ti, 14.90. Found: C, 48.71; H, 3.55; Ti, 14.78.

35 Preparation Example E

Preparation of $C_5H_3(3-SiMe_3)CMe_2Ph[TiCl_3]$, to be used in Example 8

a) Preparation of $C_5H_3(SiMe_3)_2CMe_2Ph$

To a solution of 2.25 g (11.8 mmol) $(C_5H_4CMe_2Ph)Li$ [5] in 50 ml

of diethyl ether and 20 ml of THF, cooled in ice water, 1.5 ml (1.3 g, 11.9 mmol) TMSCl was added dropwise. The mixture was allowed to warm to room temperature and was stirred overnight. The yellow solution was cooled in ice water and 4.8 ml (12 mmol) of a 2.5M n-BuLi solution in hexanes was added. After warming up to room temperature the mixture was stirred for 4 hours. The white suspension was cooled in ice water and 1.6 ml (1.4 g, 12.7 mmol) TMSCl was added dropwise. The mixture was allowed to warm to room temperature and stirred overnight. The yellow suspension was poured into 125 ml ice water. The water layer was extracted with 50 ml of light petroleum and the combined organic layers were dried on MgSO₄. After evaporation of low-boiling volatiles, the residue was distilled using a Kugelrohr-apparatus. The product distilled at 115 °C at 0.8 Torr. Yield: 2.87 g (8.7 mmol, 74%) - ¹H NMR (200 MHz, CDCl₃): δ 7.4-7.1 (m, 5H, Ph), 6.40 (d, ³J_{HH} = 2.2 Hz, 2H, Cp), 6.20 (t, ³J_{HH} = 2.1 Hz, 1H, Cp), 1.53 (s, 6H, CMe₂), -0.03 (s, 18H, TMS)

b) Preparation of [C₅H₃(3-SiMe₃)CMe₂Ph]TiCl₃

To a solution of 0.92 ml (1.6 g, 8.4 mmol) TiCl₄ in 50 ml of methylene chloride, cooled at -50 °C, 2.75 g (8.4 mmol) of C₅H₃(SiMe₃)₂CMe₂Ph was added. The reaction mixture was allowed to warm to room temperature and was stirred overnight. The volatiles were removed in vacuo and the residue was stripped with pentane. Extraction with methylene chloride and cooling down to -60 °C afforded 2.76 g (6.7 mmol, 80%) of the desired compound. - ¹H NMR (300 MHz, C₆D₆): δ 7.1-6.85 (m, 5H+1H, Ph+Cp), 6.57 (m, 1H, Cp), 6.53 (m, 1H, Cp), 1.63 (s, 6H, CMe₂), 0.12 (s, 9H, TMS) - ¹³C NMR (75.4 MHz, C₆D₆): δ 158.5 (Ph C ipso), 148.5 (Cp C ipso), 144.1 (Cp C(TMS) ipso), 128.7, 128.6, 126.7, 126.1, 124.6 (Ph+Cp CH), 41.2 (CMe₂ ipso), 29.3, 29.0 (CMe₂), -0.8 (TMS) - Anal. Calcd for C₁₇H₂₃SiTiCl₃: C, 49.84; H, 5.66; Ti, 11.69. Found: C, 49.70; H, 5.68; Ti, 11.59.

Preparation example F

Preparation of [C₅H₃(3-SiMe₃)CMe₂-3,5-Me₂C₆H₃]TiCl₃, to be used in

35 Example 9

a) Preparation of C₅H₃(SiMe₃)₂CMe₂-3,5-Me₂C₆H₃

To a solution of 1.15 g (5.3 mmol) [CpCMe₂-3,5-Me₂C₆H₃]Li in 50 ml of diethyl ether, cooled with ice water, 0.7 ml (0.6 g, 5.5 mmol) trimethylsilyl chloride was added dropwise. The reaction mixture was

allowed to warm to room temperature and was stirred overnight. The white suspension was cooled to $-30\text{ }^{\circ}\text{C}$ and 5.4 mmol of a 2.5M solution of n-BuLi in hexanes was added dropwise. After stirring for 3 hours at ambient temperature, the reaction vessel was placed in ice water and 0.8 ml (0.7 g, 6.4 mmol) trimethylsilyl chloride was added. The reaction mixture was allowed to warm up to room temperature and was stirred overnight. The mixture was poured into 100 ml of ice water. The water layer was extracted twice with 50 ml portions of light petroleum, and the combined organic layers were dried over MgSO_4 . Kugelrohr-distillation at $160\text{ }^{\circ}\text{C}$ and 0.4 Torr yielded 1.26 g (3.5 mmol, 66%) of the title compound - ^1H NMR (200 MHz, CDCl_3): δ 6.90 (s, 2H, Ar o-H), 6.78 (s, 1H, Ar p-H), 6.37 (m, 2H, Cp), 6.19 (m, 1H, Cp), 2.24 (s, 6H, ArMe), 1.51 (s, 6H, CMe_2), -0.05 (s, 18H, TMS)

b) Preparation of $[\text{C}_5\text{H}_3(3\text{-SiMe}_3)\text{CMe}_2\text{-}3,5\text{-Me}_2\text{C}_6\text{H}_3]\text{TiCl}_3$

To a solution of 0.35 ml (0.6 g, 3.2 mmol) titanium chloride in 40 ml of methylene chloride, cooled at $-40\text{ }^{\circ}\text{C}$, 1.18 g (3.3 mmol) of $\text{C}_5\text{H}_3(\text{SiMe}_3)_2\text{CMe}_2\text{-}3,5\text{-Me}_2\text{C}_6\text{H}_3$ was added dropwise. The reaction mixture was allowed to warm to room temperature and was stirred overnight. The volatiles were removed in vacuo and the residue was stripped with pentane. Extraction with pentane yielded 1.02 g (2.3 mmol, 72%) of light-brown crystals. - ^1H NMR (300 MHz, C_6D_6): δ 6.96 (m, 1H, Cp), 6.69 (s, 2H, Ar o-H), 6.64 (m, 1+1H, Cp + p-H), 6.55 (m, 1H, Cp), 2.08 (s, 6H, ArMe), 1.70 (s, 6H, CMe_2), 0.13 (s, 9H, TMS) - ^{13}C NMR (75.4 MHz, C_6D_6): δ 159.1 (Ar C ipso), 148.5 (Cp C ipso), 144.1 (Cp C(TMS) ipso), 137.9 (Ar m-C ipso), 128.8, 128.4, 127.8, 124.7 (Cp CH + Ar p-CH), 124.1 (Ar m-H), 41.2 (CMe_2 ipso), 29.3, 29.2 (CMe_2), 21.5 (ArMe), -0.9 (TMS)

Preparation example G

30 Preparation of $(\text{C}_5\text{H}_4\text{CMe}_2\text{Ph})\text{Ti}(\text{CH}_2\text{Ph})_3$, to be used in Example 10

To a stirred solution of 0.52 g of $(\text{C}_5\text{H}_4\text{CMe}_2\text{Ph})\text{TiCl}_3$ (1.54 mmol) in 30 ml of diethyl ether, cooled at $-40\text{ }^{\circ}\text{C}$, a solution of benzyl magnesium bromide (4.62 mmol) in diethyl ether was added dropwise. The mixture was allowed to warm to room temperature and was stirred for 3 hours. The solvent was removed in vacuo. The red solid was extracted with pentane. Cooling to $-40\text{ }^{\circ}\text{C}$ yielded red crystals of the desired product (560 mg, 1.11 mmol, 72%) - ^1H NMR (500 MHz, C_6D_6): δ 7.17-7.11 (m, 10H, Ph m-and o-H and Bz m-H), 7.02 (m, 1H, Ph p-H), 6.90 (t, $^3\text{J}_{\text{HH}} = 7.5\text{ Hz}$, 3H, Bz p-H), 6.81 (d, $^3\text{J}_{\text{HH}} = 7.5\text{ Hz}$, 6H, Bz o-

H), 5.74 (ps. t, $^3J_{HH} = 2.8$ Hz, 2H, Cp), 5.50 (ps. t, $^3J_{HH} = 2.8$ Hz, 2H, Cp), 2.97 (s, 6H, Ti-CH₂), 1.38 (s, 6H, CMe₂) - ^{13}C -NMR (125.7 MHz, C₆D₆): δ 149.6 (s, Ph C ipso), 149.1 (s, Bz C ipso), 146.7 (s, Cp C ipso), 128.8 (dd, $^1J_{CH}=158$ Hz, Bz m-CH, overlap with solvent), 128.5 (d, $^1J_{CH}=151$ Hz, Ph m-CH, overlap with solvent), 127.0 (dm, $^1J_{CH}=161$ Hz, Bz o-CH), 126.5 (dm, $^1J_{CH}=156$ Hz, Ph o-CH), 126.4 (dm, $^1J_{CH}=156$ Hz, Ph p-CH), 123.0 (dt, $^1J_{CH}=160$ Hz, Bz p-CH), 118.4 (dm, $^1J_{CH}=168$ Hz, Cp CH), 113.5 (dm, $^1J_{CH}=172$ Hz, Cp CH), 93.5 (t, $^1J_{CH}=123$ Hz, Ti-CH₂), 40.5 (s, CMe₂), 30.2 (q, $^1J_{CH}=122$ Hz, CMe₂) - Anal. Calcd for C₃₅H₃₆Ti: C, 83.32; H, 7.19; Ti, 9.49. Found: C, 82.63; H, 7.32; Ti, 9.35.

Preparation example H

Preparation of [C₅H₃-1,3-(CMe₂Ph)₂]₂TiCl₃, to be used in Example 15

a) Preparation of [C₅H₃-1,3-(CMe₂Ph)₂]₂Li

To a suspension of 2.28 g (27.1 mmol) PhLi in 50 ml of n-hexane, 6.14 g (27.4 mmol) of 3- α,α -dimethylbenzyl-6,6-dimethylfulvene was added. The mixture was refluxed for 5 hours. The precipitate was poured onto a glass frit and rinsed with 2x 20 ml of pentane. Drying in vacuo yielded 4.18 g (13.6 mmol, 50%) of the title compound as an off-white solid. - ^1H NMR (300 MHz, C₆D₆/THF-d₈): δ 7.55 (d, $^3J_{HH} = 8.2$ Hz, 4H, Ph o-H), 7.16 (m, 4H, Ph m-H), 7.01 (m, 2H, Ph p-H), 5.87 (m, 1H, Cp), 5.83 (m, 2H, Cp), 1.79 (s, 12H, CMe₂) - ^{13}C NMR (75.4 MHz, C₆D₆/THF-d₈): δ 154.9, 129.0 (Ph and Cp C ipso), 127.8, 126.7, 124.7 (Ph CH), 100.8, 99.8 (Cp CH), 39.8 (CMe₂ C ipso), 32.5 (CMe₂).

b) Preparation of [η^5 -C₅H₃-1,3-(CMe₂Ph)₂]₂TiCl₃

To a solution of 1.31 g (4.2 mmol) of [C₅H₃-1,3-(CMe₂Ph)₂]₂Li in 30 ml of methylene chloride, cooled at -40 °C, 0.47 ml (0.8 g, 4.2 mmol) TiCl₄ was added dropwise. The dark brown solution was allowed to warm to room temperature and was stirred overnight. The solvent was removed in vacuo and the residue was stirred with 40 ml of pentane, which was subsequently pumped off. The residue was extracted with 50 ml of toluene, which was replaced by a 1:1 mixture of methylene chloride/pentane (30 ml in total). Cooling to -40 °C afforded 0.22 g (0.5 mmol, 12%) of the title compound. - ^1H NMR (300 MHz, C₆D₆): δ 6.98 (m, 2H, Ph p-H), 6.96 (m, 4H, Ph m- or o-H), 6.70 (m, 4H, Ph m- or o-H), 6.50 (m, 1H, Cp), 6.40 (d, $^3J_{HH} = 2.6$ Hz, 2H, Cp), 1.60 (s, 6H, CMe₂), 1.54 (s, 6H, CMe₂) - ^{13}C NMR (75.4 MHz, C₆D₆):

δ 156.2, 148.8 (Ph and Cp C *ipso*), 128.4, 126.5, 126.0 (Ph CH), 121.5, 120.5 (Cp CH), 41.7 (CMe₂ C *ipso*), 28.5, 28.4 (CMe₂) - Anal. Calcd for C₂₃H₂₅TiCl₃: C, 60.62; H, 5.53. Found: C, 60.16; H, 5.56.

5 **Example 1: Catalytic ethene conversion with (C₅H₄CMe₂Ph)TiCl₃/MAO**

The reactions were performed in a stainless steel 1L autoclave (Medimex), fully temperature and pressure controlled and equipped with solvent and catalyst injection systems. In a typical experiment, the autoclave was evacuated and heated for 45 min at 90 °C prior to
10 use.

The reactor was then brought to the desired temperature, charged with 200 ml of toluene and pressurized with ethene. After equilibrating for 15 min, the appropriate amount of MAO/toluene was injected together with 25 ml of toluene. Subsequently a mixture of
15 2.50 g cyclooctane (internal standard) and 1.0 ml (0.87 g) of a 15 mM stock solution of the titanium complex in toluene was injected, together with 25 ml of toluene, to start the reaction. During the run the ethene pressure was kept constant to within 0.2 bar of the initial pressure by replenishing flow. After the specified run time,
20 the reactor was vented and the residual MAO was destroyed by addition of 20 ml of ethanol. Samples of the reaction mixture were taken to analyze and quantify the soluble components. Polymeric product was stirred for 90 min in acidified ethanol and repeatedly rinsed with ethanol and light petroleum on a glass frit. The polymer was
25 initially dried in air and subsequently in vacuo at 70 °C overnight.

The results of the catalytic experiments are summarized in Table 1 (ethene conversion with the (C₅H₄CMe₂Ph)TiCl₃/MAO catalyst system) and Table 2 (ethene conversion with the (C₅H₄CMe₂Ph)TiCl₃/MAO catalyst system).

30 In these experiments, the C₆ fraction consists predominantly of 1-hexene (99+ %), with traces of 2- and 3-hexenes. The only detectable product of the C₈ fraction is 1-octene. The C₁₀ fraction is a mixture of isomers with either vinyl (90%), vinylidene (5%) or internal olefinic (5%) unsaturation, and consists predominantly of 5-
35 methylnon-1-ene (75-85%). Higher olefins (C₁₂-C₂₄) constitute less than 0.5 wt% of the total amount of product formed.

Table 1:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
1	0.2	30	8.0 (87)	0.1 (0.8)	1.0 (11)	0.2 (1.6)	1066
2	0.5	30	20.9 (83)	0.3 (1.2)	3.5 (14)	0.5 (1.8)	2787
3	1.0	30	47.2 (86)	0.9 (1.6)	5.1 (9)	1.4 (2.6)	6292
4	0.5	50	12.4 (83)	0.2 (1.1)	1.6 (11)	0.7 (4.6)	1653
5	0.5	80	3.3 (76)	0.05(0.9)	0.2 (4)	0.8 (19)	440

Toluene solvent, 15 µmol Ti, Al:Ti = 1000, 30 min run time

5

Table 2:

Test nr.	Run time min	Al:Ti	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
6	15	1000	16.6 (89)	0.2 (1.0)	1.4 (8)	0.4 (2.2)	4413
7	30	1000	20.9 (83)	0.3 (1.2)	3.5 (14)	0.5 (1.8)	2787
8	60	1000	27.1 (80)	0.4 (1.2)	5.5 (16)	0.9 (2.7)	1809
9	30	500	15.2 (86)	0.2 (1.2)	1.8 (10)	0.5 (2.8)	2029

10 Toluene solvent, 15 µmol Ti, 30 °C, 0.5 MPa ethene

Comparative example A: Catalytic ethene conversion with (C₅H₄CMe₃)TiCl₃/MAO

The general procedure and conditions of example 1 were followed, using the (C₅H₄CMe₃)TiCl₃/MAO catalyst system. The results of the catalytic experiment are listed in Table 3.

Table 3:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
a	0.5	30	0.5 (17)	0.1 (3)	0.1 (4)	2.4 (76)	72

20

Example 2: Catalytic ethene conversion with (C₅H₄CMe₂-3,5-Me₂C₆H₃)TiCl₃/MAO

The general procedure and conditions of example 1 were followed, using the (C₅H₄CMe₂-3,5-Me₂C₆H₃)TiCl₃/MAO catalyst system. The results of the catalytic experiments are listed in Table 4.

Table 4:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
10	0.5	30	7.9 (94)	0.02 (0.2)	0.4 (5)	0.1 (1.3)	1052
11	0.5	50	4.5 (93)	0.03 (0.6)	0.2 (4)	0.1 (2.1)	599

Example 3: Catalytic ethene conversion with $(C_5H_4SiMe_2Ph)TiCl_3/MAO$

The general procedure and conditions of example 1 were followed, using the $(C_5H_4SiMe_2Ph)TiCl_3/MAO$ catalyst system. The results of the catalytic experiments are listed in Table 5. Higher olefins ($C_{12}-C_{24}$) are also formed, constituting about 8 wt% of the total amount of product formed.

10 Table 5:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	C ₁₂ -C ₂₄ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
12	0.5	30	2.1 (36)	0.3 (5)	0.4 (7)	0.5 (8)	2.6 (44)	284
13	0.5	50	2.6 (47)	0.4 (7)	0.4 (7)	0.4 (7)	1.7 (32)	352

Example 4: Catalytic ethene conversion with $(C_5H_4CH_2Ph)TiCl_3/MAO$

The general procedure and conditions of example 1 were followed, using the $(C_5H_4CH_2Ph)TiCl_3/MAO$ catalyst system. The results of the catalytic experiments are listed in Table 6. Higher olefins ($C_{12}-C_{24}$) are also formed, constituting about 9 wt% of the total amount of products formed.

20

Table 6:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	C ₁₂ -C ₂₄ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
14	0.5	30	2.7 (42)	0.4 (6)	0.6 (9)	0.6 (9)	2.2 (34)	361
15	0.5	50	3.0 (54)	0.3 (6)	0.5 (9)	0.5 (9)	1.2 (22)	405

Example 5: Catalytic ethene conversion with $(C_5H_4Ct_2Ph)TiCl_3/MAO$

The general procedure and conditions of example 1 were followed, using the $(C_5H_4Ct_2Ph)TiCl_3/MAO$ catalyst system. The results of the catalytic experiments are listed in Table 7.

30 Table 7:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
16	0.5	30	18.5 (88)	0.05 (0.3)	1.4 (7)	1.0 (4.6)	2462
17	0.5	50	8.7 (84)	0.03 (0.3)	0.6 (5)	1.0 (9.9)	1159

Example 6: Catalytic ethene conversion with $\{CpC[(CH_2)_5]Ph\}TiCl_3/MAO$

The general procedure and conditions of example 1 were

35

followed, using the $\{C_5H_4C[(CH_2)_5]Ph\}TiCl_3/MAO$ catalyst system. The results of the catalytic experiments are listed in Table 8.

Table 8:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
18	0.5*	30	24.4 (87)	0.1 (0.3)	2.9 (10)	0.6 (2.0)	3248
19	0.5*	50	12.0 (86)	0.1 (0.4)	1.2 (9)	0.7 (5.2)	1593
20	0.5**	30	16.4 (91)	0.04 (0.2)	1.4 (8)	0.2 (1.3)	4362

5

* 30 min run time, ** 15 min run time

Example 7: Catalytic ethene conversion with $[C_5H_4C(=CH_2)Ph]TiCl_3/MAO$

The general procedure of example 1 was followed, using the $[C_5H_4C(=CH_2)Ph]TiCl_3/MAO$ catalyst system. The conditions and results of the catalytic experiments are listed in Table 9.

Table 9: Catalytic ethene conversion with the $[C_5H_4C(=CH_2)Ph]TiCl_3/MAO$ system (toluene solvent, 15 μmol Ti, Al:Ti = 1000, 30 min run time)

15

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
21	0.5	30	17.3 (88)	0.1 (0.3)	1.4 (7)	0.9 (4.7)	2307
22	0.5	50	10.9 (86)	0.03 (0.2)	0.7 (6)	1.1 (8.3)	1449

Example 8: Catalytic ethene conversion with $[C_5H_3(3-SiMe_3)CMe_2Ph]TiCl_3/MAO$

The general procedure and conditions of example 1 were followed, using the $[C_5H_3(3-SiMe_3)CMe_2Ph]TiCl_3/MAO$ catalyst system. The results of the catalytic experiments are listed in Table 10.

Table 10:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
23	0.5	30	25.2 (85)	0.6 (2.1)	3.3 (11)	0.4 (1.2)	3357
24	0.5	50	20.1 (84)	0.4 (1.5)	3.3 (14)	0.3 (1.3)	2683
25	0.5	80	8.0 (88)	0.1 (1.4)	0.8 (8)	0.2 (2.1)	1069

25

Example 9: Catalytic ethene conversion with $[C_5H_3(3-SiMe_3)CMe_2-3,5-Me_2C_6H_3]TiCl_3/MAO$

The general procedure and conditions of example 1 were followed, using the $[Cp(TMS)CMe_2-3,5-Me_2C_6H_3]TiCl_3/MAO$ catalyst system. The results of the catalytic experiments are listed in Table

30

11. For the run at 30°C, the C₆ fraction consists of 99.9% 1-hexene, and the C₁₀ fraction of 94% 5-methylnon-1-ene.

Table 11:

5

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
26	0.5	30	40.1 (84)	0.1 (0.2)	7.0 (15)	0.3 (0.6)	5347
27	0.5	50	25.7 (82)	0.1 (0.3)	4.8 (15)	0.6 (1.9)	3427

Example 10: Catalytic ethene conversion with (C₅H₄CMe₂Ph)Ti(CH₂Ph)₃/MAO

The general procedure and conditions of example 1 were followed, using the (C₅H₄CMe₂Ph)Ti(CH₂Ph)₃/MAO catalyst system. The results of the catalytic experiments are listed in Table 12.

Table 12:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
28	0.5	30	23.8 (82)	0.3 (1.1)	4.6 (16)	0.5 (1.6)	3175
29	0.5	50	18.6 (78)	0.3 (1.1)	4.0 (17)	0.8 (3.3)	2480

15

Example 11: Catalytic ethene conversion with (C₅H₄CMe₂Ph)TiMe₃/MAO

The general procedure and conditions of example 1 were followed, using the (C₅H₄CMe₂Ph)TiMe₃/MAO catalyst system. The results of the catalytic experiment are listed in Table 13.

Table 13:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
30	0.5	30	25.7 (81)	0.4 (1.2)	5.2 (16)	0.5 (1.5)	3428
31	0.5	50	18.1 (79)	0.2 (1.0)	3.8 (17)	0.7 (3.2)	2412

25

Example 12: Catalytic ethene conversion with (C₅H₄CMe₂Ph)TiMe₃/MAO/SiO₂

The reaction was performed in a stainless steel 1 l autoclave (Medimex), fully temperature and pressure controlled and equipped with solvent and catalyst injection systems. Prior to use the autoclave was preheated in vacuo for 45 min at 90 °C. The reactor was

30

cooled to 30 °C, charged with 200 ml of toluene and pressurized with ethene. After equilibrating for 15 min, a slurry of 2.05 g of 5 wt% MAO/SiO₂ in 10 ml of toluene was injected together with 30 ml of toluene. Subsequently a mixture of 2.50 g cyclooctane (internal standard) and 1.0 ml (0.87 g) of a 15 mM stock solution of (C₅H₄CMe₂Ph)TiMe₃ in toluene was injected, together with 25 ml of toluene, to start the reaction. During reaction the ethene pressure was kept constant to within 0.2 bar of the initial pressure by replenishing flow. After 30 min the reactor was vented and the remaining residual MAO was destroyed by addition of 20 ml of ethanol. Samples of the reaction mixture were taken to analyze and quantify the soluble components. The solids (polyethene and silica support) were stirred in acidified ethanol for 90 min and rinsed repeatedly with ethanol and light petroleum on a glass frit. The material was dried in air overnight and subsequently in vacuo at 70 °C overnight, yielding 1.7 g of which the polyethene fraction was not determined. The results of the catalytic experiment are listed in Table 14; the conditions were: toluene solvent, 15 µmol Ti, Al:Ti = 250, 30 min run time. Weight percentages calculated on C₆-C₁₀ products only.

Table 14:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
32	0.5	30	13.8 (95)	0.1 (0.8)	0.6 (4)	n.d.	1837

Example 13: Catalytic ethene conversion with (C₅H₄CMe₂Ph)TiMe₃/[PhNMe₂H][B(C₆F₅)₄]

The reactions were performed in a stainless steel 500 mL autoclave (Medimex), fully temperature and pressure controlled and equipped with solvent and catalyst injection systems. Prior to use the autoclave was preheated in vacuo for 45 min at 90 °C. The reactor was cooled to the desired temperature, charged with 150 ml of toluene and pressurized with ethene. After equilibrating for 15 min, a suspension of 16.5 µmol [PhNMe₂H][B(C₆F₅)₄] in 5 ml of toluene was injected together with 25 ml of toluene. Subsequently a mixture of 2.50 g cyclooctane (internal standard) and 1.0 ml (0.87 g) of a 15 mM stock solution of the titanium trimethyl complex in toluene was injected, together with 25 ml of toluene, to start the reaction. During reaction the ethene pressure was kept constant to within 0.2

bar of the initial pressure by replenishing flow. After the desired run time, the reactor was vented and samples of the reaction mixture were taken to analyze and quantify the soluble components. The polymer was repeatedly rinsed with ethanol and light petroleum on a glass frit. The polymer was dried in air overnight and subsequently dried in vacuo at 70 °C overnight. The results of the catalytic experiments are listed in Table 15. The conditions were: toluene solvent, 15 μmol Ti, B:Ti = 1.1, 30 min run time

10 Table 15:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
33	0.5	30	14.6 (90)	0.2 (1.3)	1.2 (7)	0.3 (2.0)	1948
34	0.5	50	14.0 (82)	0.2 (1.1)	2.2 (13)	0.6 (3.4)	1867

Example 14: Catalytic ethene conversion with (C₅H₄CMe₂Ph)TiMe₃/B(C₆F₅)₃

15 The reaction was performed in a stainless steel 500 mL autoclave (Medimex), fully temperature and pressure controlled and equipped with solvent and catalyst injection systems. Prior to use the autoclave was preheated in vacuo for 45 min at 90 °C. The reactor was cooled to the desired temperature, charged with 150 ml of toluene and pressurized with ethene. After equilibrating for 15 min, 1.0 ml (0.87 g) of a 16.5 mM stock solution of B(C₆F₅)₃ in toluene was injected together with 25 ml of toluene. Subsequently a mixture of 2.50 g cyclooctane (internal standard) and 1.0 ml (0.87 g) of a 15 mM stock solution of the titanium trimethyl complex in toluene was injected, together with 25 ml of toluene, to start the reaction. During reaction the ethene pressure was kept constant to within 0.2 bar of the initial pressure by replenishing flow. After the desired run time, the reactor was vented and samples of the reaction mixture were taken to analyze and quantify the soluble components. The polymer was repeatedly rinsed with ethanol and light petroleum on a glass frit. The polymer was dried in air overnight and subsequently dried in vacuo at 70 °C overnight. The results of the catalytic experiment are listed in Table 16. The conditions were: toluene solvent, 15 μmol Ti, B:Ti = 1.1, 30 min run time.

Table 16:

Test nr.	P(ethene) MPa	T °C	C ₆ g (wt%)	C ₈ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
35	0.5	30	5.8 (88)	0.1 (0.9)	0.3 (5)	0.4 (6.6)	776

5 Example 15: Catalytic ethene conversions with [C₅H₃-1,3-(CMe₂Ph)₂]TiCl₃/MAO

The general procedure and conditions of example 1 were followed, using the [C₅H₃-1,3-(CMe₂Ph)₂]TiCl₃/MAO catalyst system. The results of the catalytic experiments are listed in Table 17.

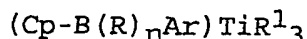
10

Table 17:

Test nr.	P(ethene) MPa	T °C	Run time min	C ₆ g (wt%)	C ₁₀ g (wt%)	PE g (wt%)	Productivity kg(C ₆) mol(Ti) ⁻¹ h ⁻¹
36	0.5	30	30	11.9 (91)	0.6 (5)	0.3 (2.3)	1575
37	0.5	30	120	46.6 (89)	4.1 (8)	0.8 (1.5)	1550

1. A catalyst system for the selective trimerization of olefins comprising a transition metal complex characterized in that said catalyst system comprises

- a) a half-sandwich substituted cyclopentadienyl titanium complex
5 of formula



wherein

Cp is a cyclopentadienyl type ligand, optionally substituted,

B is a bridging group, based on a single atom selected from
10 the groups 13 to 16 inclusive of the Periodic System,

Ar is a aromatic group, optionally substituted,

R is, independently, hydrogen, or a hydrocarbon residue,
optionally being substituted and optionally containing
heteroatoms, or groups R and B are joined together to form
15 a ring,

n is an integer equal to the (valency of B minus 2), and

R¹ is a mono-anionic group, and

- b) an activator.

20 2. A catalyst system according to claim 1, wherein the single atom forming the basis of group B is selected from B, C, N, O, Si, P and S.

3. A catalyst system according to any of the claims 1 or 2
25 wherein the single atom forming the basis of said group B consists of carbon or silicon,

Ar is phenyl, optionally substituted or being part of a larger aromatic entity,

R¹ is a halide, or mono-anionic hydrocarbon residue optionally
30 containing heteroatoms, and

n is 2, then R is a mono-anionic hydrocarbon residue, optionally containing heteroatoms, or

n is 1, then R is a di-anionic hydrocarbon residue, optionally containing heteroatoms.

35 4. A catalyst system according to any of the claims 1 to 3, wherein Cp is a cyclopentadienyl type ligand being substituted,

besides said B-(R)_n group, with 1 to 8 groups of formula -YR₂R₃R₄ in which Y is C or Si and R₂, R₃ and R₄ are, independently, H, halogen, lower alkyl, aryl, lower-alkyl-aryl, aryl-lower alkyl residue, wherein said alkyl and aryl are independently substituted or not with one or more lower alkyl residues, said alkyl and aryl residues being independently provided or not with at least one heteroatom, selected from halogen, nitrogen, oxygen, sulphur and phosphor.

5. A catalyst system according to any of the claims 1 to 4, wherein said lower alkyl residues, being the same or different to each other, are linear or branched C₁-C₅ alkyl residues, more specifically methyl.

6. A catalyst system according to any of the claims 1 to 5, wherein said aryl group in the alkylaryl or arylalkyl residue is a phenyl group.

7. A catalyst system according to any of the claims 1 to 6, wherein said halogen is fluorine or chlorine.

8. A catalyst system according to any of the claims 1 to 7, wherein

Ar is a phenyl group, substituted or not at the meta-or para-position,

B is based on a carbon atom,

n is 2, then groups R are, independently, methyl, or ethyl; or

n is 1, then group R is =CH₂, or forms when R is C₄H₈ or C₅H₁₀

together with group B a dianionic cyclic group

Cp is C₅H₄ or C₅H₃(SiMe₃), or C₅H₃(CMe₂Ph), and

R¹ is chlorine, methyl, or benzyl.

9. A catalyst system according to any of the claims 1 to 8, wherein said catalyst complex is supported on a carrier.

10. A catalyst system according to any of the claims 1 to 9, wherein said activator is methylalumoxane, a salt of a non-coordinating anion, or a Lewis acid capable of abstracting an anion from said transition metal complex.

11. A catalyst system according to any of the claims 9 and 10 wherein the activator is methylalumoxane and the molar ratio of Ti:Al is from 1:100 to 1:1000.

5

12. A catalyst system according to any of the claims 1 to 11, wherein said catalyst system further comprises a scavenger.

13. A catalyst system according to claim 12, wherein said
10 scavenger is selected from $i\text{-Bu}_3\text{Al}$ and $(i\text{-Bu}_2\text{Al})_2\text{O}$.

14. A process to trimerize olefinic compounds, which comprises carrying out said trimerization in the presence of a catalyst system according to any of the preceding claims under trimerization
15 conditions.

15. A process according to claim 14, wherein said olefin is selected from $\text{C}_2\text{-C}_{20}$ olefins or mixtures of two or more of these olefins.

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C07C2/32 B01J31/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C07C B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, CHEM ABS Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 608 447 A (PHILLIPS PETROLEUM CO) 3 August 1994 (1994-08-03) cited in the application claims 20-24	14, 15
X	SASSMANNSHAUSEN J ET AL: "HALF-SANDWICH COMPLEXES OF TITANIUM AND ZIRCONIUM WITH PENDANT PHENYL SUBSTITUENTS. THE INFLUENCE OF ANSA-ARYL COORDINATION ON THE POLYMERISATION ACTIVITY OF HALF-SANDWICH CATALYSTS" JOURNAL OF ORGANOMETALLIC CHEMISTRY, ELSEVIER-SEQUOIA S.A. LAUSANNE, CH, vol. 592, 1999, pages 84-94, XP001033815 ISSN: 0022-328X cited in the application table 1	1-13
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *G* document member of the same patent family

Date of the actual completion of the international search

22 April 2002

Date of mailing of the international search report

29/04/2002

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Goetz, G

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 94 25416 A (SHELL INT RESEARCH) 10 November 1994 (1994-11-10) page 2, line 14 -page 3, line 4 -----	14,15

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
EP 0608447	A	03-08-1994	AU	650808 A1	30-06-1994
			CA	2087578 A1	20-07-1994
			CZ	9300088 A3	17-08-1994
			JP	3188335 B2	16-07-2001
			JP	6239920 A	30-08-1994
			NO	930340 A	02-08-1994
			EP	0608447 A1	03-08-1994
			AT	207084 T	15-11-2001
			DE	69330943 D1	22-11-2001
			DE	69330943 T2	11-04-2002
			DK	608447 T3	11-02-2002
			ES	2161699 T3	16-12-2001
WO 9425416	A	10-11-1994	AU	683060 B2	30-10-1997
			AU	6650394 A	21-11-1994
			BR	9406460 A	30-01-1996
			CA	2161664 A1	10-11-1994
			CN	1121704 A ,B	01-05-1996
			CZ	9502826 A3	15-05-1996
			DE	69405222 D1	02-10-1997
			DE	69405222 T2	02-01-1998
			DK	696263 T3	29-09-1997
			WO	9425416 A1	10-11-1994
			EP	0696263 A1	14-02-1996
			FI	955104 A	26-10-1995
			JP	8509518 T	08-10-1996
			NO	954292 A	26-10-1995

BEST AVAILABLE COPY

THIS PAGE BLANK (USPTO)